

From Huh? to Aha! – a modern and thrilling approach to the user experience of structural measurements

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Abstract

Does this bridge require maintenance? Is it worth for me, as an investor, to purchase this building? In order to answer such questions, data is collected with specialized instruments, evaluated by experts and passed through the hands of many people with varying levels of expertise. Understanding the stakeholders is a key element in both efficiency and error prevention. Screening Eagle Technologies is not only known in the industry for its technical innovations and has received multiple awards, but also for the ease of use of the measuring devices and the data processing software. The article introduces how, based on an amazingly simple operating metaphor, we consistently use AI, 3D and AR to help our users avoid mistakes and work efficiently when collecting, interpreting and passing on complex measurement data.

Keywords and Phrases: Interaction design theory, concepts and paradigms, Mixed / augmented reality, Artificial intelligence, Camera metaphor

1 Introduction

The buildings, bridges, and other infrastructure around us are built primarily of concrete. And concrete is aging. After around 30 to 40 years defects caused by structural deterioration may reach a critical size, that in the end could cause a building to collapse. Hence, regular and thorough structural investigations of built objects like buildings or bridges are imperative in order to detect defects and repair them in time. Or look at an investor who thinks about whether to buy an existing building. It is in their interest to know the structural health of the object of interest before agreeing on the price and signing the contract. Again, this requires structural investigations. A structural investigation involves measuring data with special instruments,

it means looking deep into the concrete with technology like radar, ultrasound or eddy current. All of these technologies come with the big advantage of being completely non-destructive. It is analogous to a medical checkup: we prefer the doctor to look via ultrasound into our belly instead of an invasive procedure. Such a structural investigation involves several parties. In the case of a regular health inspection for a building this would involve the regulating authorities to check on the owners following the regulations, the owner of a building wanting to be in accordance with law and knowing the state of the building, an engineer to assess the collected data and propose measures to the building owner, and a field inspector collecting the data. Other inspections like an as-built check right after construction involve additional people like the architect and the construction manager.

In assessing the structural health of a built object errors can be critical and life threatening. A precise and reliable measurement, clear interpretation, precise localization and a shared understanding of the results by the involved people of different level of expertise are key to prevent errors and work efficiently.

In the following, we will focus on one example technology, the technology of ultrasound.

2 Challenges of structural investigations

2.1 A structural investigation with ultrasound

There are three key measurements that can be taken in the field in the course of a structural investigation with ultrasound:

A *Line Scan* is used for rapid detection of subsurface objects and defects, such as voids and cracks. Basically, the inspector is looking deep into the wall along a line, to see a cross section perpendicular to the scan. The instrument has several transducers in a row and thereby can measure a length of 21 cm per shot. This means, a longer line must be measured by combining shots collected in sequence and integrating them into a single image (see figure 1). For a quick first glance there can be a distance between the shots, whereas a more

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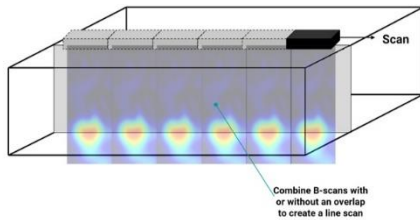
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Line Scan



Stripe Scan

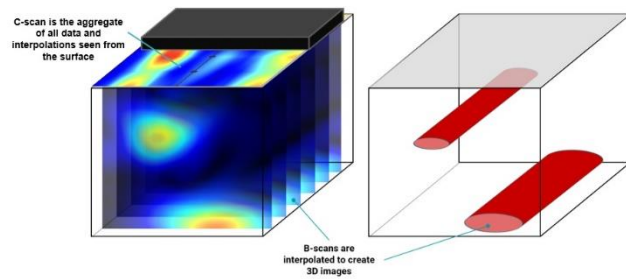


Figure 1: The measurement principle of a Line Scan and a Stripe Scan

Grid Scan

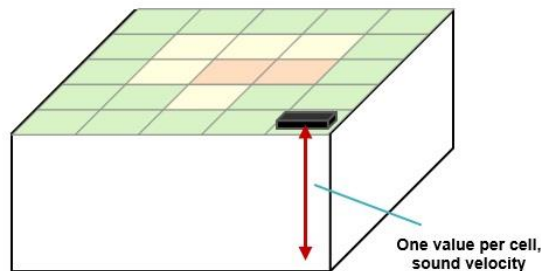


Figure 2: The measurement principle of a Grid Scan

detailed look will require the individual shots to be stitched together or even overlapped. The idea is like merging a panorama picture out of several photos.

With a *Stripe Scan* one aims at creating a 3D image of the subsurface structure. In this case the short lines the probe measures are taken in sequence, but rather one above the other, resulting in a 21 cm wide stripe of parallel lines. If the distance between the lines is not more than 10 cm, then interpolation will allow to fill in the gaps, resulting in a 21 cm wide 3D image (see [figure 1](#)).

For checking on the quality of a large concrete wall a *Grid Scan* is used. The measuring takes place in a grid pattern with one shot per cell. Out of all the information contained in the data only the velocity of the reflected sound is extracted and shown color-coded for this cell ([figure 2](#)). Poor quality concrete hinders the sound waves and lowers their velocity, so a low velocity is indicating bad concrete quality.

2.2 The initial user experience

Let us first have a look how an ultrasound measurement for the evaluation of the structural integrity and the localization of flaws and voids in concrete (sounds quite complicated, doesn't it?) looked like for an inspector some years ago (see [figure 3](#)):

- Arriving onsite, marking out the measurement positions on the wall with ruler and chalk
- While measuring, place the device precisely on the marked-out positions and record the data
- For contextual information, take pictures with a camera and take notes
- After measurement, download the data files from the processing unit to the PC via USB stick
- Transfer all other data (photos, notes) also to the PC
- Integrate everything into a report



Figure 3: An ultrasound investigation some years ago

This workflow comes with certain pain points:

- Marking out the positions is time consuming
- The exact placement of the probe while measuring is time consuming and prone to errors
- Extracting the velocities during a Grid Scan is repetitive and takes time
- Manual data transition is prone to data loss and errors
- Bringing all the data together is time consuming
- The pictures are not easy to understand for non-experts
- Relating the pictures to a real-world situation requires significant mental effort
- Cables hindering range and movement

2.3 The dream of the future experience

In the past, there were limits to the available portable computational power, which resulted in the rather bulky processing unit and the workflow as described above. Nowadays, even an average tablet has sufficient processing power to handle AR and 3D imagery on a brilliant display. And we are all used to share our files cable free and expect our data to be safe and accessible from everywhere in the cloud. And we don't want to handle several devices anymore when we can have it all in one in our mobiles.

What, if we would make use of this new power and use a lightweight tablet with a brilliant screen to not only show the data in a crystal-clear way but also to easily save and share them? What if we would make use of the built-in rich functionality of a tablet to not only further enhance the data presentation and add context but also make it easier to collect and interpret the data? And what if the resulting software would feel as lightweight and cool as a popular app?

3 Improving the overall user Experience with a metaphor

3.1 Why a metaphor?

Piling up features and adding more and more functionalities will not result in a usable solution, but rather, in a complicated, overwhelming experience. An inherently complex task with numerous possible actions needs a strong and task fitting logic that gives it a structure the user can easily understand. This is where metaphors come into play.

Metaphors have been applied in the field of human computer interaction since its very beginning and became ubiquitous because of their power and effect. Who does not know windows or folders? Or skeuomorphism and material design? A metaphor is an idea used to present another idea. Usually, a more familiar and concrete idea is used to make an abstract, less well-known concept more accessible and understandable. Metaphors link all the pieces together in a natural way [1, 2].

3.2 What metaphor for structural measuring?

What metaphor could make structural measuring easier for the inspector? Let us have an abstracted look on the actions an inspector must take. First, the inspector needs to tell the system certain settings for the measurement to be taken, then record the data and finally do some post-processing on the data to get the best image which he can share with the engineer afterwards. The measured data are images, pictures in 2D. Which means, recording structural data means taking pictures. And these pictures can be post-processed to get the best possible look. There happens to be a well-known pattern for taking pictures with a tablet: the mobile camera app.

Everybody can use the camera app without lengthy explanations. It is straightforward and simple. What is characteristic of it? (1) The picture as the object of interest is occupying the full screen, (2) the main action button, "record", is highly prominent, a round button in the middle of the right-

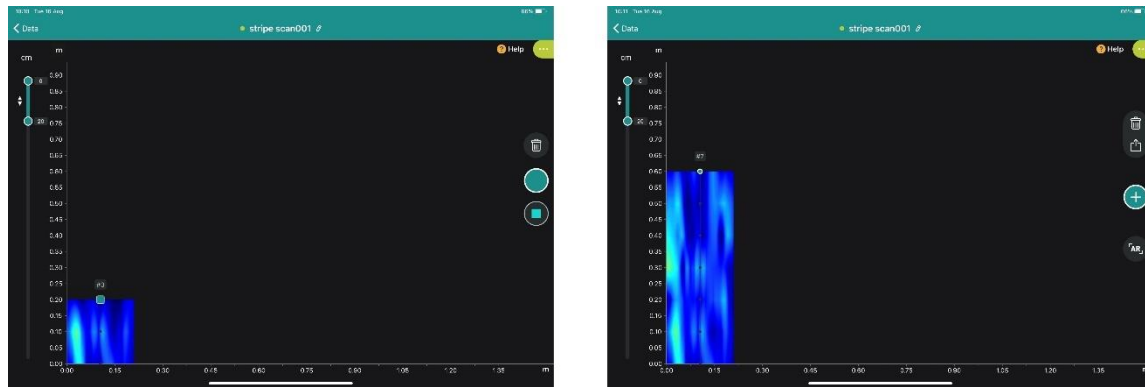


Figure 4: The camera app metaphor applied to the data recording (left) and post-processing (right) of a Stripe Scan

hand side, (3) the settings are de-emphasized, they are available via toolbars above and below the main action button, (4) the successful recording is clearly indicated, with a thumbnail.

3.3 Extending the metaphor

As good as this metaphor is, it falls short. It is in the very nature of the camera app to only focus on recording pictures, everything else is left to separate apps. Such an approach makes sense for photos. Photos are often left unchanged, only a few are selected for improvement by post-processing, therefore a separate app for doing so is ok. On the other hand, the data from an ultrasound measurement are usually subject to post-processing to achieve the best possible image that is easiest to analyze. The post-processing is ideally done already onsite to get a first glimpse on the results. Having two separate apps would mean a breakdown in the workflow every time. With this the question arises of how we could integrate the processing and analyzing part into the camera app metaphor?

We solved this via abstracting the key characteristics of the camera app: (1) The picture area is dominating the screen and covers most of it, (2) the main action buttons in the workflow are highly prominent, they are round button(s) in the middle of the right-hand side, (3) the settings are de-emphasized, quick interactions on the data area are provided in a toolbar above and below the main action button, other settings are deeper hidden in an expandable side menu, (4) the picture is building up continuously while measuring, so the inspector is always aware that the recording was successful (see [figure 4](#)).

4 making data recording and analyzing easier with AI

4.1 Why AI?

Exact placement of the probe and repetitive analyzing are part of the challenges the inspector is facing. This is where AI can help.

For both Line Scan and Stripe Scan the picture is built from the single shots taken. For correctly merging the single shots the

system needs to know, where these shots are located in relation to each other. In the classic workflow the inspector is marking the measurement position with chalk on the wall and tells the system the distance between the shots. And while measuring the inspector must place the device exactly over the previously marked out positions. This does not only cost time but is also prone to errors. A method for recognizing the position of the probe would come in helpful here.

A Grid Scan requires the inspector to look at the data in each cell and to determine the position of the backwall, which is used by the system to calculate the sound velocity that is indicative for the concrete quality. Often the backwall is rather obvious for an experienced inspector. But still the position of the backwall has to be manually indicated, which takes time, is repetitive and not fully accurate. An algorithm that automatically detects the backwall and immediately shows the velocity as the value of interest would come in very useful.

4.2 Simple and advanced AI functionality

Artificial intelligence (AI) is understood as “the ability of a digital computer or computer-controlled robot to perform tasks commonly associated with intelligent beings” [3]. This includes intellectual processes such as recognizing patterns, reasoning, discovering meaning, generalizing, and learning. These processes come with a big difference in complexity and difficulty to master for the computer. Also, what was seen as a challenge for the computer yesterday is hardly seen as AI nowadays. While pattern recognition as used for optical character recognition (OCR) is rather on the simple side, the reliable identification of objects in ultrasound data is rather ambitious.

However, what matters when delegating tasks to AI functions is controllability, reliability, and speed. Imagine you delegate an important and time critical task to another person because you have a full to-do list already. If this person delivers good results to you in the same or less time as you would have needed, then you would be fully satisfied with this person. Getting the results long after you would have needed them would be pointless. And

getting them fast but in bad quality just doubles your efforts. Does this mean the other person must be as good as you are in doing the task? For simple tasks the answer is yes. For complex tasks the situation is a different one. If the other person could quickly deliver a good portion of the results in good quality, leaving you to only fill in the remainder, then this could save you a lot of time. A satisfying experience would require the standard cases to be reliably done by the other person and the to-dos for you being clearly visible.

The same goes if you delegate to a system instead of to another person.

4.3 An AI solution for structural measurements

The AI-tape allows the inspector a comfortable way of preparing the wall and placing the probe while measuring. The tape is self-adhesive and is simply attached to the wall along the line to be measured. While measuring, the camera integrated into the probe recognizes the actual position of the probe and the data are shown at the actual position (see [figure 5](#)). Also, the automated position recognition comes with an additional advantage on top of the gain in accuracy and efficiency, namely flexibility. Now, there is no more need for the inspector to decide beforehand whether he is after a quick coarse scan with wider gaps between the shots or a more time-consuming full coverage to avoid missing any details. With the tape, the inspector can first do a coarse scan, have a look at the result and then decide where to take additional shots for more details.

This is clearly a simple task. Therefore, we aimed for and achieved a detection rate near 100% for a correct placement within the generous tolerance of the probe camera's sensitive field. The control is provided via a little camera window on the tablet screen and a misplacement is signaled by a sound. However, the inspector cannot manually correct the position., but considering the extremely high detection rate this is not needed.

Automatically detecting the backwall for the velocity calculation is rather on the ambitious side. For achieving the desired user experience, we invested significant effort into the algorithm so that it is reliably able to recognize every standard case. Beside reliability, speed and controllability are key. The inspector always sees the data and the back wall position determined by the system in real time for the current cell. This way a quick side glance assures the inspector that the result is correct. Of course, the inspector can correct the backwall position manually. Also, in the tricky cases where the system was not able to determine the backwall at all, then the inspector can indicate its position manually. This not only puts the inspector in full control, but constantly seeing the correctness of the algorithm also builds trust into it.

5 Communicating with non-experts and relating data and real world with 3D and AR

5.1 Why AR?

Communicating the results to non-experts and relating them to the real world belong to the challenges the inspector is facing.

During a structural measurement on site, the inspector is performing his task in both the real and digital worlds. The inspector is marking out the area to be measured on the wall, is following the marks while recording with the probe and is observing the incoming data on the digital screen. The immersion of the inspector is only in the real world.

The digital data record provides a deeper (in a literal sense) understanding of the real-world object. The real world is the context to make sense of the colourful picture on the screen. It is in the inspector's mind where this connection is made and it is the inspector's working memory's processing capacity that is used to make this connection. As soon as the inspector leaves the site, this immediate connection between the two worlds becomes lost. This does not only cost the inspector more time afterwards



Figure 5: Measuring a Line Scan with the help of the AI tape. The circle in the bottom right corner of the iPad screen shows the camera image

to relate the data to the real world again but also makes it more difficult to communicate the results to somebody who was not on site. This is especially true for non-experts, who anyway have difficulties making sense of the data.

This is where AR comes in. The AR is making the connection, bridging the gap between the two worlds. Instead of using the working memory the inspector can now simply look at the scene and by taking a screenshot, this integrated scene can even be recorded and kept for later.

5.2 Heuristics for a good AR usability

Augmented reality (AR) provides experiences that overlay graphics, video streams, or holograms in the physical world. For comparison, a virtual reality (VR) occludes the user's view and presents a fully immersive digital experience. Experiences in between are called mixed reality (MR). For example, if the user can interact with the digital objects projected to real world as if they were physically present, then this is mixed reality [4]. Which means, in a pure augmented experience the digital objects keep their digital nature and are not naturalized.

When using tablets or another handheld mobile device, then the device works like a window the user is looking through at the real world.

Applications that incorporate augmented or virtual realities pose specific challenges to their usability. These challenges are reflected in specific heuristics for AR and MR [5] of which the relevant ones for the subject at hand are:

- Easy identification of where to start and easily getting started
- Positive experience
- Easily accessible help for the app and handling of the device
- Minimized cognitive overload and no unnecessary clutter
- Easy identification which virtual elements are interactive

- No obstruction of critical physical objects by virtual objects
- Simple, easy to understand, and easy to complete interactions overall

The emphasis on the easy interactions and getting started is not surprising, same goes for the minimizing of a cognitive overload. Usually, the user is performing a tricky task in physical reality, like assembling a product or repairing a machine. It is the intention of AR to provide the user with help and guidance. However, if the task itself is already straining for the user, then it is mandatory for everything additional like AR to blend in naturally or at least to be easy and straightforward.

5.3 Getting started with the AR in the structural measurement application

Entering AR should be easy and straightforward. To make the entrance easy to perceive we gave it a prominent position, AR is one of the action buttons in the always visible toolbar. Also, the function only appears if the current view is suitable for an AR projection which is the case for Stripe Scan and Grid Scan, and only after a measurement is finished (see [figure 4](#)).

The biggest hurdle is to place the marker, which is necessary for a precise positioning. Many fun applications do not care about this step, because it does not matter exactly where the projection appears. However, for a structural investigation this step cannot be avoided because the marker establishes a point of reference between the real and digital world. To make it clear to the user what to do, a pop up showing the AR marker appears automatically during first time use and a little animation demonstrates how to move the iPad around the marker to get the projection started (see [figure 6](#)). Intuitively, a user would place the marker in the bottom left corner because zero is the usual point of reference. The design of the marker shows its orientation. For a Grid Scan it will be horizontally, so that the text is in proper orientation. For a Stripe Scan the adumbrated AI tape on the marker gives the hint how to position it.

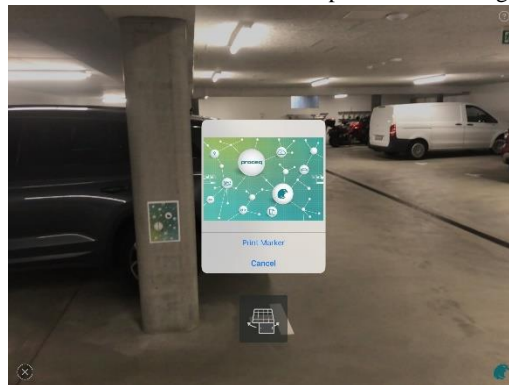


Figure 6: The pop up for getting the AR started, showing the marker as a reminder. Below the popup there is the little animation showing what to do with the iPad

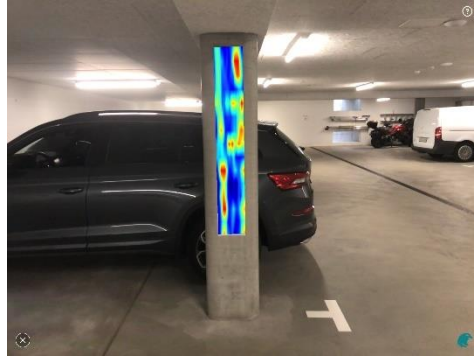


Figure 7: Stripe Scan C-scan image projected onto a column

5.4 Digital objects and interactions in AR

In a Stripe Scan two digital objects can be projected into the real world, the rather abstract C-scan and a 3D image. The inspector sees these data presentations on the tablet screen, in the digital world. When calling the AR, these exact digital objects are projected into the context of the real world. Both objects keep their digital nature.

To achieve an immersive experience, the marker was given a size so that the projection of the digital object would completely cover it (see [figure 7](#)).

Obstruction can occur in two ways: by the marker and by the image. The marker can be removed once the projected image appears. For handling the obstruction caused by the picture, the inspector can control the opacity of it via a horizontal finger movement. While some users immediately found this out, others were not aware of this functionality. Being aware of this functionality is the hurdle here. Once discovered, users considered it intuitive and easy to recall. Making the existence of the opacity adaptation function visible remains an issue to be improved for the user experience.

The C-scan image is difficult to understand because it is the projection of the aggregated data of a defined depth slice to the surface, with the slider near the left border being the UI element to set the depth slice (see [figure 4](#)). On the contrary, the translation of the data into a 3D iso surface is much easier to understand because the objects become visible (compare [figures 7](#) and [8](#)). In the app, the user can freely rotate the 3D image. For AR, the 3D image is normalized in perspective when projected into the real world and its circumscribing cube appears as a hole for a natural appearance (see [figure 8](#), left). As for obstruction, the digital object obstructing the real world is not relevant for this 3D case, because its purpose is illustrating and understanding what is going on below the surface. However, being in a sunken hole makes the hole obstructing for the 3D object. Therefore, for better visibility the user can pull the 3D object out of the hole with an intuitive vertical finger movement and then go around it as desired to view it from all sides (see [figure 8](#), right). The 3D AR projection is the perfect tool when communicating the results to non-experts. Aside adapting the opacity, there is only one other interaction: a vertical two finger swipe toggles between the C-scan and the 3D object in the app and in AR.

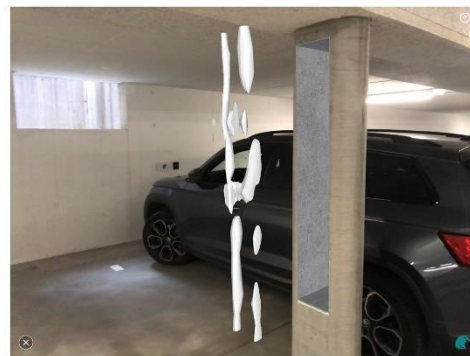
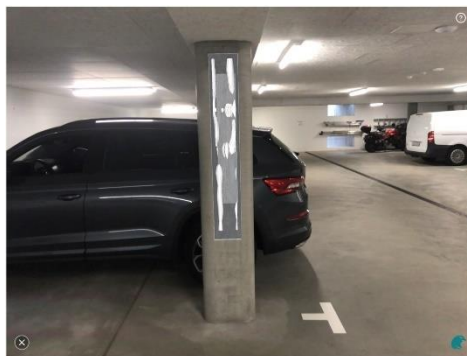


Figure 8: Stripe Scan 3D image projected onto the column. Original projection (left) and pulled out structure (right)

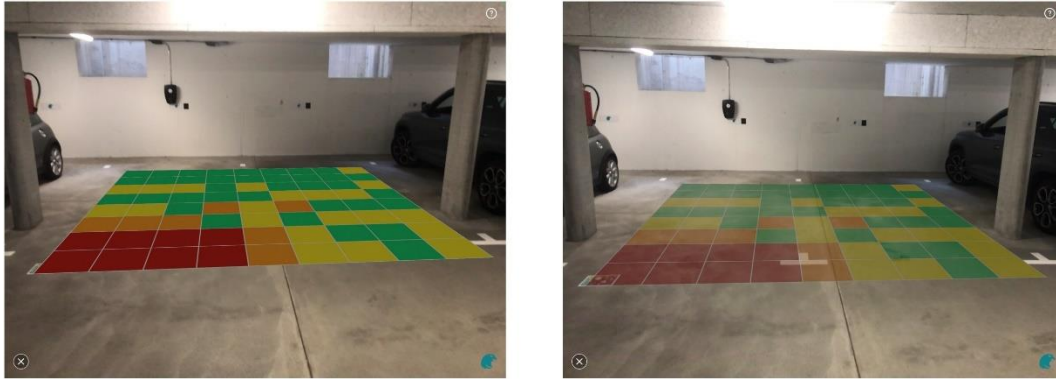


Figure 9: Grid Scan in AR. Opaque (left) and half transparent (right)

The data cell grid in the Grid Scan can also be projected into the real world and allows the inspector to adapt its opacity (see [figure 9](#)).

A challenge we had to overcome was the drift of the image with respect to the marker. While fun applications don't need to care about this, a sufficient precision is essential for a structural investigation. The effort our specialist team put into this issue finally paid off. While for big objects and larger distance it is slightly noticeable (but still within tolerance), it is almost eliminated for smaller objects and distances (compare [figures 7](#) and [8](#) versus [figure 9](#)).

The AR we designed and implemented does not aim for fanciness but is fully focused on the task to be solved. The limited number and intuitiveness of the possible interactions put the principle of making it easy to understand and complete interactions into practice.

6 Conclusion

The goal was to create a modern, thrilling way of recording, analyzing, and sharing data for the inspector of a structural investigation with ultrasound. For achieving this goal, we made use of the latest technology how it is provided in a handy format in the iPad. But we refrained from just piling up fancy features.

Our way was to group the functionality around a well-known and easy metaphor. Instead of fanciness, we reduced the new technology to the essentials as needed in the workflow and integrated it into the flow of the app. Seamlessly integrated reliable AI algorithms save the inspector time and avoid human errors. And a well guided AR gives the data context and helps the inspector communicating the results to non-experts. The result is a cool app the inspectors love, and an ultrasound measurement for the evaluation of the structural integrity and the localization of flaws and voids in concrete becomes (almost) as easy as taking pictures with the iPad camera.

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